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# CXLS IONIZING AND LASER RADIATION SAFETY INTERLOCK SYSTEMS *

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*Abstract*

The Compact X-ray Light Source (CXLS) requires the acceleration of electrons to relativistic energies, which collide with focused IR laser pulses to produces x-rays which are then transported to the experiment hutch. A class 4 UV laser is used at the photocathode to liberate the electrons that are generated via the photoelectric effect. During electron acceleration bremsstrahlung radiation (gamma and neutron) is generated through electron interactions with solid matter. In the experiment hutch the x-rays then interact with the sample under test in pump-probe configuration where the pump laser is another class 4 laser with a wide spectral range from deep UV to THz. Interlock systems have been designed and deployed to protect users of the facility from exposure to these ionizing and laser radiation hazards. Here we describe the architecture of CXLS interlock systems where we make clear what systems are independent, and which are interdependent and what administrative override modes are made available and why. We also provide an overview of our monthly interlock system testing protocols and conclude with comments on overall system performance.

## INTRODUCTION

The CXLS beamline is comprised of VAULT-1, RF-1, LASER-1, HUTCH-1, VAULT-1 CONTROL, and HUTCH-1 CONTROL. Figure 1 shows the facility layout.

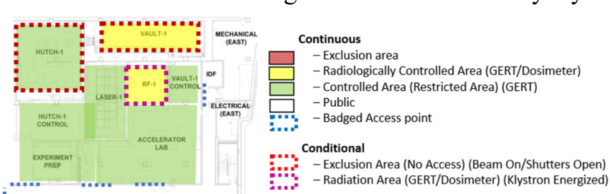


Figure 1: CXLS facility overview of controlled areas.

The equipment housed in the facility has the capacity to generate harmful forms of radiation. CXLS radiation hazards are identified in Table 1. Due to shield wall penetrations, all rooms adjacent to VAULT-1 must be monitored for ionizing radiation.

Table 1: CXLS Hazards

| Location | Microwave | Ionizing | Laser |
|---|---|---|---|
| VAULT-1 | ✓ | ✓ | ✓ |
| RF-1 | ✓ | ✓ | |
| LASER-1 | | | ✓ |
| HUTCH-1 | | ✓ | ✓ |

The CXLS ionizing and laser radiation personnel protection interlock system is designed to ensure the safety of laboratory personnel. Strategically placed area monitors throughout the CXLS laboratory continuously monitor radiation status. Relay-based logic is employed to determine if safety conditions are met and to establish the appropriate interlock status. If safety conditions are not met, the interlocks force the system into a user-safe condition. In high-risk areas like VAULT-1 and HUTCH-1, where ionizing radiation hazards are present, rooms must be searched and secured before CXLS operation can proceed. This is implemented through dependent search button chains that must be pressed sequentially and within a specific timeframe. Aggregator panels are used in the interlock system to interconnect relay logic and timers, ensuring the ability to secure a perimeter. These features collectively help to manage radiation to ALARA [1] (As Low As Reasonably Achievable) limits for personnel exposure. Additionally, ionizing radiation E-stop buttons are strategically placed throughout the CXLS facility. If any E-stop button is pressed, the primary interlock arming chain breaks, causing the transmitters to lose power and stopping the source of ionizing radiation.

## RADIATION DETECTION

Radiation detection is critical for achieving ALARA [1] limits. Area monitors are distributed throughout the CXLS laboratory to monitor radiation status. Relay-based logic is used to determine if the safety conditions are met. If safety conditions are not met, the interlocks will force the system into a user-safe condition. Figure 2 outlines the locations of all radiation monitoring equipment.

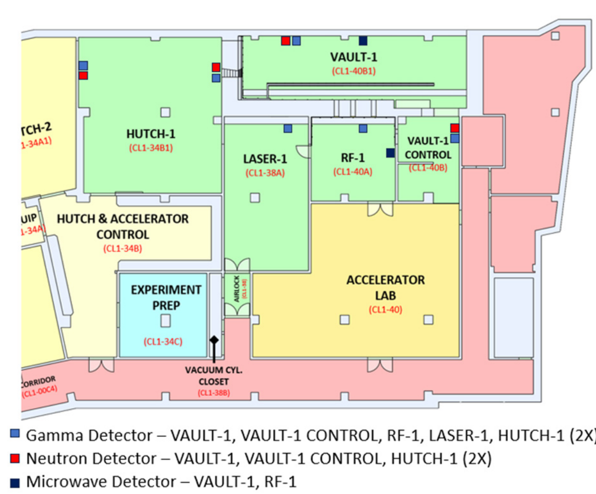


Figure 2: Map of radiation area monitoring equipment in the CXLS facility.

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For gamma and neutron detection an Apantec [2] ratemeter systems which communicates with via a MODBUS TC/IP protocol through EPICS [3] to monitor the radiation levels are used. In our accelerator vault an ion chamber gamma detector and $BF_3$ neutron detector that can properly handle the high intensity radiation fields is deployed to monitor full intensity prompt radiation. In adjacent laser and RF rooms high range Geiger-Muller detectors are deployed. In the vault control room, and in two locations in our experiment hutch wide area Geiger-Muller detectors and He-3 neutron detectors are deployed.

Microwave energy is generated in the RF room and conveyed through RF waveguide to accelerator structures in the vault. Narda [4] SMARTS II microwave radiation area monitors are positioned near these structures to detect any leakage. If any perimeter area monitors detect radiation exceeding preset ALARA bounds the primary interlock chain will be broken and the RF transmitters will be disabled causing immediate cessation of prompt radiation.

## INTERLOCK SYSTEM ARCHITECTURE

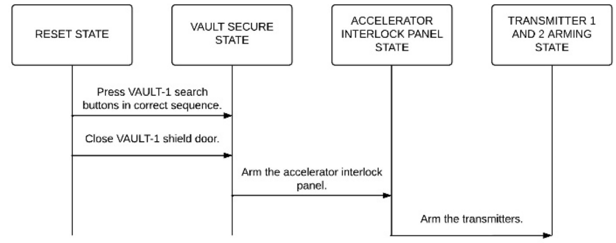
Radiation hazards are managed through engineering controls using two independent interlock systems: 1) ionizing radiation, and 2) laser radiation. Interlock systems follow strict use protocols. If use protocols are not followed the interlocks are reset to a user-safe state and the user must start again. Selected interlock systems can be put into an administrative override state while performing administrative alignment actions. This allows for administrative protocols to be applied under strict supervision.

### *Ionizing Radiation Interlock Architecture*

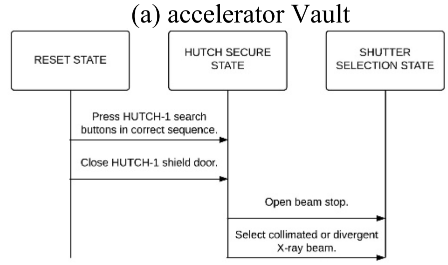
Bremsstrahlung radiation is generated in the vault during normal operation. Extensive engineered shield wall system and beam stoppers are employed to protect adjacent spaces. Gamma and neutron area monitors are used to monitor all adjacent spaces. Occupation of the experiment hutch is not allowed when double tungsten shutters are lifted and x-ray beam is allowed to pass from the vault to the hutch.

Prior to e-beam and x-ray beam generation in the vault a search procedure is performed, and the perimeter is secured with the shield door closed with double sensor interlock verification. Prior to allowing x-ray introduction to the experimental hutch a search procedure is performed and the perimeter is secured with shield door closed and double verification sensors interlocked.

The vault and hutch have interlock panels that display interlock status. In the vault, once the room is secured, the accelerator interlock panel can be armed, and each transmitter can be individually armed. Once a transmitter is armed RF energy can be transmitted to the vault accelerating structures. If the vault perimeter is broken, then the transmitters will be immediately inhibited. In the hutch, once the room is secured, the double tungsten shutters may be opened individually, either for the collimated or free divergent x-ray beam. If the hutch perimeter is broken, then the double tungsten are instantly closed, and the e-beam is inhibited. Figure 3 outlines the arming sequence for vault and hutch systems.




(a) accelerator Vault




(b) Experimental Hutch

Figure 3: High-level overview of ionizing interlock system functionality.

### *Laser Interlock Architecture*

Laser interlocks are implemented using the modular interlock system provided by Laser Safety Systems [5]. The IR laser in LASER-1 is exported to VAULT-1 where an interlocked enclosure is implemented in order to enable a Class 1 environment in VAULT-1 when the enclosure remains closed. The safety chain for the IR laser is likewise extended to VAULT-1 in order to interlock to the source of the laser hazard. Any exposed laser work performed in LASER-1, VAULT-1, or HUTCH-1 requires that the entire room be transitioned to a laser lab. Once transitioned to a laser lab a key code is required for room access. When transitioned to a laser lab state lasers may be armed. Lasers used in either VAULT-1 or HUTCH-1 are fully enclosed in a light tight enclosure with interlocked doors to create a Class 1 environment. Enclosure doors can be opened without tripping the interlock only if an administrative override is performed. Any protocol violation drives the interlock system to a safe state. Figure 4 outlines the functionality of the laser interlocks system for the user.

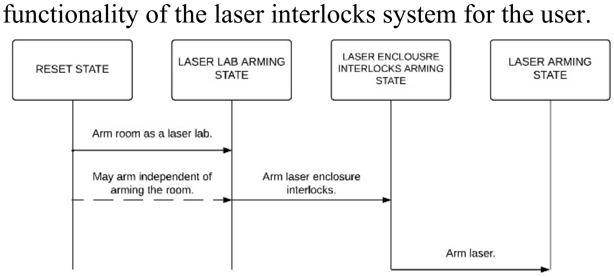



Figure 4: High-level overview of laser interlock system functionality.

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## IONIZING RADIATION MEASUREMENT

The first experiment measured the gamma and neutron ionizing radiation levels throughout the vault and adjacent occupied areas. Utilizing data collected with an electron beam energy range of 26-29 MeV and a bunch charge of 10 nA, we extrapolated the expected levels of ionizing radiation for the commissioning specifications of 200 nA, Figure 5 shows the extrapolated dose rates. This extrapolated data was used to compare to simulations provided to us by XELERA [6]. Extrapolated values were found to agree within approximately a factor of 4.

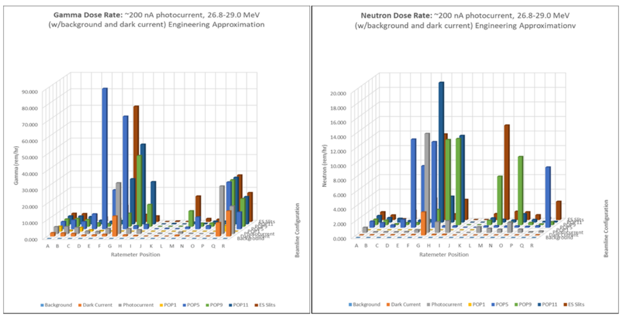


Figure 5: Experiment one extrapolated radiation dose rate for gamma and neutron radiation at 200 nA beam current.

The second experiment was conducted to assess the ionizing radiation levels in the hutch and CXLS experiment chambers when tungsten shutters are open and closed. Ionizing radiation detectors were strategically placed inside the hutch adjacent to the penetration, inside the experiment chamber, and behind the detector chamber. The aim of this experiment was to quantify the extent of ionizing radiation propagating through and around the beam pipe to evaluate the potential radiation exposure to the Eiger [7] X-ray detector and personnel, and to further validate the utility of XELERA [6] simulations. The findings from this experiment, Fig 6, indicate that when shutters are open ionizing radiation does enter the hutch at low levels, as expected. This indicates that additional localized shielding will be required for the Eiger detector and personnel safety. All operating modes examined are performed with full prior coordination with the Arizona State University Environmental Health and Safety Radiation Safety Officer. Periodic updates are provided to the ASU Radiation Safety Committee on facility progress and operating modes.

## AGGREGATOR PANELS

Interlock aggregator panels are used to manage the hardwired connection of safety relays, timer relays, area monitors, and e-stops. Panels are in VAULT-1, VAULT-1 CONTROL, RF-1, LASER-1, and HUTCH-1.

Relay logic is used to perform interlock system functions. Safety relays from IDEM [8] (SCR-21-i and SCR-31-i) are used in order to provide redundant function to the interlock chains. Relay based logic was chosen over other forms like programmable logic controllers, logic cards, or field programmable gate arrays due to the simplicity and reliability they provide. These features, and the diagnostic LEDs located on the face of the relays makes maintaining the interlock system much simpler.

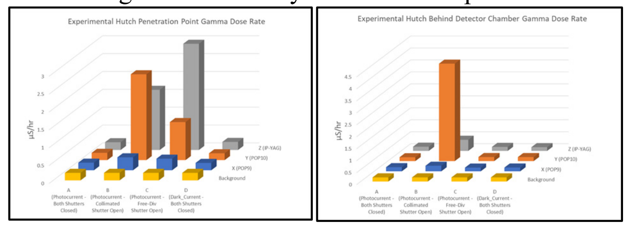


Figure 6: Dose rates in the experimental hutch as a function of tungsten shutter open/closed status.

## TESTING PROTOCOLS

Every month the entire interlocks system is tested to verify that the system behaves as expected when users follow the standard operating procedures, and that the system responds correctly to all possible violations of these procedures. This protocol is broken down into subsections, first testing the facility wide ionizing radiation e-stops, the area monitoring equipment, and the vault and hutch ionizing radiation interlocks. Then the laser interlock systems are tested for the laser lab, vault, and hutch. All ionizing and laser radiation e-stop loops are tested for functionality every month; however, it is only tested twice a year to verify that e-stops will crash its corresponding equipment, that being the transmitters or one of the lasers.

## CONCLUSION

In conclusion, the CXLS features an advanced interlock system that protects users from ionizing radiation and laser hazards. This system utilizes sensors, actuators, and logic controls to ensure laboratory safety by monitoring and managing the CXLS suite's operational parameters. It distinguishes between ionizing and laser radiation, offering tailored response mechanisms for each hazard. Aggregator panels facilitate troubleshooting, enhancing system reliability. Administrative override modes provide flexibility for testing and maintenance without sacrificing safety protocols. Regular monthly testing of the interlock system emphasizes a commitment to safety and ongoing performance improvement. Overall, the CXLS interlock system's design reflects a balanced approach to operational efficiency and rigorous safety standards, successfully mitigating exposure to hazardous conditions through careful planning and design.

## REFERENCES

[1] ALARA, `https://www.nrc.gov/reading-rm/basic-ref/glossary/alara.html`

[2] Apantec, `http://www.apantec.com/`

[3] EPICS, `https://epics.anl.gov/index.php`

[4] Narda, `https://www.narda-sts.com/en/`

[5] Laser Safety Systems, `https://www.lasersafetysystems.com/`

[6] XELERA Research, `https://www.xeleraresearch.com/`

[7] Eiger, `https://www.dectris.com/en/`

[8] IDEM Safety, `https://idemsafety.com/`